PCT/AU03/00288

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

AUSTRALIA

Patent Office
Canberra

REC'D 28 MAR 2003
WIPO PCT

I, SMILJA DRAGOSAVLJEVIC, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PS 1059 for a patent by UNIVERSITY OF WESTERN SYDNEY as filed on 12 March 2002.

COMMONWEALTH OF AUSTRALIA
AUSTRALIA
PATENT OFFICE

WITNESS my hand this
Twenty-first day of March 2003

S. Dragosavljevic

SMILJA DRAGOSAVLJEVIC
TEAM LEADER EXAMINATION
SUPPORT AND SALES

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant:

UNIVERSITY OF WESTERN SYDNEY

Invention Title:

CONNECTOR ASSEMBLY

The invention is described in the following statement:

CONNECTOR ASSEMBLY

The present invention relates to connectors used in attaching concrete bodies to structures, for example in composite slabs, columns, beams or any structure attached to concrete slabs, blocks, etc. In one form, the invention relates to the shear connector studs used in construction that form the main connection between a frame structure and a concrete slab.

Forming concrete composite structures in building construction involves assembling a structural framework with cross-connecting primary beams and secondary beams, and laying a ribbed decking across the supporting primary and secondary beams. Reinforcing bars or mesh are then layed on top of the decking. Concrete is poured on top of the decking to complete the composite structure. In construction works the structural framework is usually made of steel. Figure 1 illustrates an example of a steel/concrete composite slab. When the concrete hardens and reaches sufficient compressive strength, the decking provides the main reinforcement for the concrete slab and the slab becomes the top flange of the composite beam.

Shear connector studs are often used to strengthen the connection between the steel framework and concrete slab. The studs are fixed, generally welded, upright through the steel decking before the concrete is poured and are placed above the primary or secondary beams. Once the studs are cast in concrete, they become an important part of the connection formed between the steel framework and concrete slab.

Depending on the profile of the decking and the nature of the studs, the strength, ductility and efficiency of the shear connection formed between the concrete slab and framework can under ultimate load conditions lead to the

common problem of rib punch-through failure.

Referring by way of example to steel/concrete composite structures, rib punch-through failure occurs when the studs are subjected to a longitudinal shear force between the concrete and steel framework. The weight of the structure and the load it supports have the effect of thrusting the concrete against one side of each stud creating concentrated stresses at the base of the stud and forming a break-away wedge in the concrete which, under the longitudinal shear force, is pushed into the ribs of the steel decking and away from the studs. This situation is illustrated in figure 2A. Arrow A indicates the direction of shear force in the concrete C against the stud S welded through decking D to steel beam SB. The break-away concrete wedge is denoted by W. With the steel stud no longer confined by concrete around its base, it can be bent relatively easily under the effects of the shearing force. This mode of failure significantly reduces the shear strength of the welded studs, making their shear force/slip behaviour brittle and overall reducing the strength of the composite structure. The likelihood of punch-through failure increases as the number of shear connectors per pan increases.

Ductility is a desirable feature of shear connector studs and in some countries it is mandatory in their national design Standards that the shear connector studs in composite structures be ductile. Ductility can be assessed according to the relationship between the shear force and slip, where the slip occurs longitudinally between the concrete slab and steel beams. The slip is indicated in figure 2A by Arrow B. The definition of a ductile shear connector stud is one having a characteristic slip capacity exceeding 6 mm. Noting that slip capacity in a solid slab increases with shank diameter, studs with certain dimensions are considered

ductile. For example, some national design Standards code accept a headed stud as being ductile if the stud has an overall length after welding of at least 4 times the shank diameter, and with a diameter of not less than 16 mm and not exceeding 22 mm.

Areas most prone to cracks and wedges forming in concrete slabs or structures are regions close to edges or voids. Examples of voids include profiled ribbing on steel decking creating notch-like voids in the concrete body, while hollow cores in pre-cast concrete also create voids. Of the open or closed type variety of steel decking ribs the more significant problems are associated with the open type ribs which are more responsible for creating notch-like voids in the concrete body.

Rib punch-through failure occurs predominantly in secondary beams, that is beams spanning effectively perpendicular to the decking ribs, because with secondary beams the thrust forces are directed across the ribbed decking and are thus more likely to carry the effects of voids in the ribs to the stud shanks between the ribs. The concrete layer in composite structures is generally in compression whilst the steel beams underneath are in tension. Accordingly, the compressive force in the concrete reduces from the middle of a beam, where the moments are greatest, to the ends of the beams where the moments reduce to zero. This describes a composite beam in positive bending, but longitudinal shear forces also develop in the negative moment regions in continuous composite beams which can also lead to rib punch-through failure. In primary beams the phenomenon of rib punch-through failure is less likely because the shear forces run parallel to the decking ribs and therefore the rib voids are less likely to affect the studs between the ribs. This is not to say that rib punch-through failure does not occur in primary beams because even though the

shear force runs parallel to the decking ribs, concrete surrounding each stud is still known to be thrust laterally to the decking sheets through the sides of the open ribs. Haunch width of the concrete can be a critical factor in this regard.

In taking the above problems into account at the design stage empirical design formulae have been developed for determining the design shear capacity of studs used in composite structures. Whilst the formulae can be of guidance for simple constructions, they are relatively inaccurate in practice.

It is thought that placing studs in pairs improves the strength of the shear connection, however quite the opposite can be found to be true with strength and ductility actually reduced due to rib punch-through failure. Greater ductility is associated with single studs centrally positioned between the ribs.

In preventing or minimising the effects of rib punch-through failure it has been known to restrain the free edges of the concrete with reinforcing bars or pre-stressed cables. However, they are only applicable to edges of concrete slabs and aside from their high costs and impracticality may not deter the formation of wedges from the decking ribs internally of the concrete block.

The above problems are not exclusive to concrete composite beams but are also found in structures where a component is attached to a concrete body through bolts or fasteners embedded in the concrete body. The connected structure may be a pole, beam, leg of a larger structure, or the like. Figure 2B illustrates such as situation where two bolts B cast in a concrete slab C connect a structural component SC to the concrete slab through a plate P to which the bolts are connected to with nuts N. With the

shear force travelling in the direction of Arrow A, a cracked wedge W is likely to form at the free edge FE of the concrete slab. The free edge has a similar effect on the casting-bolts as the voids in the composite beam examples given above, that is, the free edge is a point of weakness in the concrete where a crack may form. If a connecting bolt is located close to the free edge illustrated in figure 2B, a wedge of concrete breaking off at the free edge could weaken or dislodge concrete around the base of the embedded bolt and weaken the bolt's hold in the concrete. The resulting problem is equivalent to rib punch-through failure in composite beams.

A solution is needed to maintain the integrity and strength of composite concrete structures and overcome the adverse effects resulting from the formation of cracks and wedges in concrete composite structures.

According to the present invention there is provided a connector assembly for connecting a structural component to a concrete body wherein the connector assembly is capable of resisting shear forces between the structural component and concrete body and includes:

a fastener having a shank with one end adapted to be embedded in concrete and the other end attached to the structural component; and

an element which in use surrounds the fastener to form a barrier and is spaced from the fastener to confine the concrete around the fastener.

According to the present invention there is further provided a composite concrete structure including a concrete body connected to a structural component by way of a connector assembly, the connector assembly including:

a fastener having a shank with one end embedded in the concrete body and the other end attached to the structural component; and

an element which surrounds the fastener to form a barrier and is spaced from the fastener to confine the concrete around the fastener.

Preferably, means is provided to hold the element around the fastener, and preferably this means is a clip extending between the fastener and the element.

In one embodiment, the element may surround more than one fastener.

According to the present invention there is still further provided a shear connector for use in construction with concrete composite structures having concrete supported by decking on a structural framework, the connector including:

at least one stud adapted to be permanently fixed upright to the decking; and

an element adapted to be placed on the decking and to form a barrier surrounding at least one stud a spaced distance therefrom to confine the concrete around the stud.

Preferably, means is provided to hold the element around the stud and concentric of the stud.

According to the present invention there is further provided a composite structure having concrete supported by decking on a structural framework and a plurality of shear connectors, each connector including at least one stud adapted to be permanently fixed upright to the decking, and an element adapted to be placed on the decking and to form a barrier surrounding at least one stud a spaced distance therefrom to confine the concrete around the stud.

Preferably the element can be a ring of solid material,

specifically galvanised steel, a ring of mesh or a coil with small pitch windings.

In one embodiment, the element is annular and has a height approximately 60% - 80% the height of the ribs on the decking and ideally 70% the height of the ribs. In the embodiment of the solid steel ring, at least, the rings are cut from a length of galvanised steel tube. The rings have an outer diameter of 76 mm and a wall 2 mm thick. High tensile steel of 350 MPa proof stress is preferred over lower grade steel. The element is preferably kept centrally in position before the concrete is poured with a restraining clip, defining the means to hold the element around the stud.

The element is preferably provided with lateral cross plates on opposite sides of the element wherein the cross plates support reinforcing rods extending parallel to the decking ribs to assist in confining the concrete around the stud.

According to the present invention there is still further provided a method of forming a composite concrete structure including:

assembling a structural frame incorporating interconnected cross-beams and decking mounted on the beams;

permanently fixing shear connector studs upright through the decking and aligned with the beams;

permanently fixing an element to the decking wherein the element forms a barrier surrounding at least one stud a spaced distance therefrom; and

pouring concrete on the decking to form a composite structure.

Ideally, the method includes cutting more than one barrier from a length of steel tube. The method further includes

distancing the stud and surrounding element from the decking rib at which concrete failure is most likely to occur.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is described further by way of example with reference to the accompanying drawings by which:

Figure 1 illustrates a conventional composite structure in building construction;

Figure 2A is an illustration showing the problems associated with the prior art composite beams;

Figure 2B illustrates problems associated with another prior art composite structure;

Figure 3 is a perspective view of a connector assembly according to an embodiment of the present invention;

Figure 4 is a side sectional view of a connector assembly of the present invention;

Figure 5 is another side sectional view of the connector assembly;

Figure 6 is a side view of the connector element with a restraining clip;

Figure 7 is a sectional plan view of figure 6 taken along line 7-7;

Figure 8 is a perspective view of the connector assembly with reinforcing rods;

Figure 9 is a graph showing results of a first test involving prior art;

Figure 10 is a graph showing results of the same test as figure 9 but incorporating the present invention;

Figure 11 is a graph showing results from a second test involving the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT OF INVENTION

A connector assembly illustrated in the figures includes shear connector element 10 and a fastener that connects the components of a concrete composite structure. The connector element increases the ductility and shear strength, and therefore the shear resistance, of a fastener in a concrete composite structure by surrounding the fastener in the form of a barrier thereby confining the concrete around the fastener. In a preferred embodiment, which is the main embodiment described herein, the connector element surrounds a connector stud mounted upright on decking in a composite concrete beam. However, it is understood that the present connector assembly could apply to any composite structure involving the connection of a component to concrete using connectors embedded in the concrete.

Figure 3 illustrates a standard shear connector stud 11 welded through ribbed decking 12 to a secondary steel beam 13. A shear connector element 10 surrounds stud 11.

Figure 4 is a side sectional view of figure 3 but with the stud 11 and element 10 embedded in a bed of concrete 14. The shear connector element 10 sits on the decking pan 22 of the decking and forms a barrier surrounding the stud. More specifically, the barrier surrounds the base of the stud shank. In the preferred embodiment the decking is a steel ribbed decking and the stud is welded through the decking to the steel beam underneath.

When concrete is poured onto the decking to cover the stud 11 and element 10 it flows into a pocket 15 defined by the area enclosed by the element 10 and totally embeds both the stud and element in concrete. Placing the barrier element 10 around the stud 11 has the effect of confining the concrete around the base of the stud and preventing concrete from escaping the element confines. Accordingly, the base of the stud is securely confined regardless of the formation of cracks or wedges that would otherwise dislodge concrete from around the stud base.

In the embodiment shown the connector element 10 is an annular steel ring spaced approximately 38 mm from the axial centre of the stud. However, the element 10 need not be a solid annular barrier but can be an element forming a barrier with other characteristics and shapes. For example, the element may be an annular mesh or grid element surrounding the stud which, while still effective in confining the concrete around the base of the stud, also provides the wet concrete access to the pocket 15 to more quickly and thoroughly fill the pocket by allowing the wet concrete to flow through the holes in the mesh barrier. Similarly, the element could consist of a spiral coil surrounding the stud and having windings of a

sufficiently small pitch so as to provide a confining barrier but still allow concrete to flow in between the windings. Elements made of steel are convenient, economical and relatively simple to use, however elements made of other materials capable of forming suitable barriers are also envisaged. For example, other materials that could be used are high-strength plastic or composite materials that do not chemically react with the concrete. In the preferred embodiment the elements are steel rings, and ideally galvanised steel, that are cut from a length of steel tubing.

In the embodiment illustrated in figure 5 the base of the annular ring element is cut to accommodate interconnection lips or joints. Similarly, the element can be modified to accommodate other features of the decking such as low ribs.

To keep the elements centrally in position before the concrete is poured a restraining clip 30 illustrated in figures 6 and 7 is located on the rim 21 of the element 10. The restraining clip is similar in principle to a circlip but instead has three arms 31 substantially equally separated from each other extending outwardly from a semi-circular centre 32. Centre 32 clips around the shank 16 of stud 11 and the three arms 31 extend towards the top rim 21 of the connector element 10 and clip onto the rim 21 by way of clasps 33 at the end of each arm 31. The retaining clip is resilient such that the arms 31 are able to maintain the connector element 10 a spaced distanced from the stud 11 but allow some amount of flexibility to enable the components to be assembled and to withstand the forces of the moving wet concrete during

casting. In an alternate embodiment, the restraining clip only has two opposed arms extending from a semi-circular centre. The clip is likely to be made of a resilient plastic. As illustrated in figure 6 the circular centre 32 of the clip 30 is placed higher on the stud shank 16 than the top of the element 10 with the arms extending downwardly onto the rim 21 to in effect hold the element 10 down so that it does not displace during pouring of concrete. It is understood that the retaining clip is not the only means of centring the element around the stud and that any mechanical equivalent could work equally as well to maintain the element in the correct position before and during casting.

Bursting stresses develop in the concrete at studs or fasteners under high shear force that cause a crack to form between the stud and the void, that is, the crack forms perpendicular to the void 26 as shown in figure 4. This occurs before the formation of a wedge in the concrete. Therefore, placing a reinforcing bar across the crack caused by the bursting stresses assists in resisting formation of a wedge. Figure 8 illustrates two reinforcing rods 35 held parallel to ribs 20 on decking 12 by cross plates 36 attached laterally to connector element 10 on opposing sides of the element. Figure 4 illustrates the rods in cross-section. Cross plates 36 are welded to the connector element and contain apertures 37 through which the reinforcing rods 35 extend and are held in place. The orientation of the reinforcing rods 35 is such that when embedded in concrete they traverse a bursted seam that may form and by extending into more solid concrete the rods anchor the concrete around the stud 11. Maximum effect is achieved by placing the rods deep into

where the wedge will form and reasonably close to the web 23 of the rib.

The reinforcing rods are one way of assisting to increase the holding strength of the present connector assembly. Additionally, the head 17 of the stud 11 should be fully embedded in the concrete cover slab above the decking ribs. The relative height of the stud 11 to the top of the decking ribs 20 also affects the strength of the connector assembly. It has been found that a stud having a height of at least 40 mm above the top of the ribs 20 improves its performance. Furthermore, increasing the height of the element 10 to the height of the rib can improve the performance to that of a shear connector in a solid slab without voids.

Stud performance was tested using studs having a height of 95 mm welded through steel ribbed decking with ribs having a height of 55 mm. Figure 4 illustrates the set up of a first test with and without an element 10. In the first test a connector element 10 having a height of 40 mm and welded around the stud 11 was found to perform satisfactorily in confining the concrete around the base of the stud. Accordingly, an element height of at least 70% of the height of decking ribs 20 will sufficiently confine the concrete and prevent wedges or cracks entering the pocket 15 from above the rim 21 of the element 10. As mentioned above, an even better performance is achieved where the height of the element equals or exceeds that of the ribs. Whilst an element height of 20 mm was found to offer some improvement, it did not perform as well as the 40 mm high element tested. Logically the higher the element forming the barrier up to a height reaching the

height of the rib, the better the performance of the stud. The steel ring of the tested element had an outer diameter of 76 mm and a wall thickness of 2 mm.

Sometimes multiple studs are placed adjacent to each other on the decking pan 22 to provide increased connection strength. In this case separate elements 10 may be used to surround each stud or, alternatively, a single element having a rectangular, oval, or the like, shape is positioned to surround both studs. Inner dividing walls of the element in these situations would be provided to compartmentalise the element giving each stud its own pocket of locally confined concrete. Hence, when the concrete is poured it flows into all pockets of the element surrounding the studs. The element prevents cracks and wedges from forming inside the walls of the element.

Tests performed on the single mounted stud and decking assembly illustrated in figure 4 were performed without and with the barrier element 10 and the results are illustrated in figures 6 and 7 respectively. The shear force acting on the stud was plotted against the stud slip as defined in figure 2. The results provide an indication of the ductility of the stud and hence its performance to resist shear force. In figure 4 the shear force travels in the direction of Arrow SF.

Figure 6 illustrates the results of the single mounted stud welded to the decking substantially equidistant from the webs 23 of the decking ribs 20, illustrated in figure 4 but without the connector element 10. The graph of figure 9 shows that at the standard 6 mm slip the shear

force on the stud was approximately 53 kN.

In contrast, the same arrangement but with a circumventing connector element was tested and the results are shown in the graph of figure 10. The shear force at the 6 mm slip mark was remarkably higher at 81 kN, almost a 53% improvement on the stud without the element.

The element used in the above tests was 40 mm in height and surrounded a 95 mm high stud with its centre located 68 mm from the base of the rib web 23 at which a wedge would form. The stud was welded equidistant between the right-side rib 25 and left-side rib 24, which calculates to be 68 mm from the base of the web of the right-side rib 25.

It has been found that shear strength of studs significantly improves if the proximity of the studs to the active rib webs 23 are increased. For example figure 5 illustrates a stud located closer to the left-side rib 24 than the right-side rib 25. With the shear force travelling in the direction of Arrow SF a wedge is likely to form at the right-side rib 25. Hence, moving the stud further away from this rib 25 increases the size of the wedge of concrete that has to be dislodged around the base of a stud. Combining the increased distance between the stud and active rib with the use of the present connector element significantly increases the shear strength and ductility of the stud. The graph of figure 11 shows the results of a shear force verses slip test of a stud located 100 mm away from the right-side rib 25 as illustrated in figure 5. The stud is surrounded by a connector element 40 mm in height. The graph results show

that at the 6 mm slip mark the stud sustained a force of approximately 115 kN and finally fractured just under 120 kN, which is an extremely favourable performance as if the stud had been in a solid concrete slab without voids.

However, this optimal performance is also achievable with a higher connector element and with the stud closer to the rib.

It is noted that all of the examples and tests described herein involve longitudinal shear force in secondary composite beams, which sustain the most damage, where the beams are in positive bending. However, it is noted that failure is also likely in composite beams where longitudinal forces develop in regions of negative moments.

The advantage of placing the present connector element around the stud to form a connector assembly and encapsulate and localise concrete at the stud base produces significant and important increases in strength and ductility of the studs, and on the whole make them more robust. This in turn translates to a composite structure where the major problem of rib punch-through failure is significantly reduced or entirely avoided. Additionally, the number of connector assemblies required in composite structures can be reduced on account of the increased strength which leads to shorter installation time and less material. With the present connector assembly the composite concrete structure is able to withstand a much higher ultimate load and, with its increased structural integrity, provide a more reliable and more economical construction.

It will be understood to persons skilled in the art of the invention that many modifications may be made without departing from the spirit and scope of the invention.

FIGURE 1

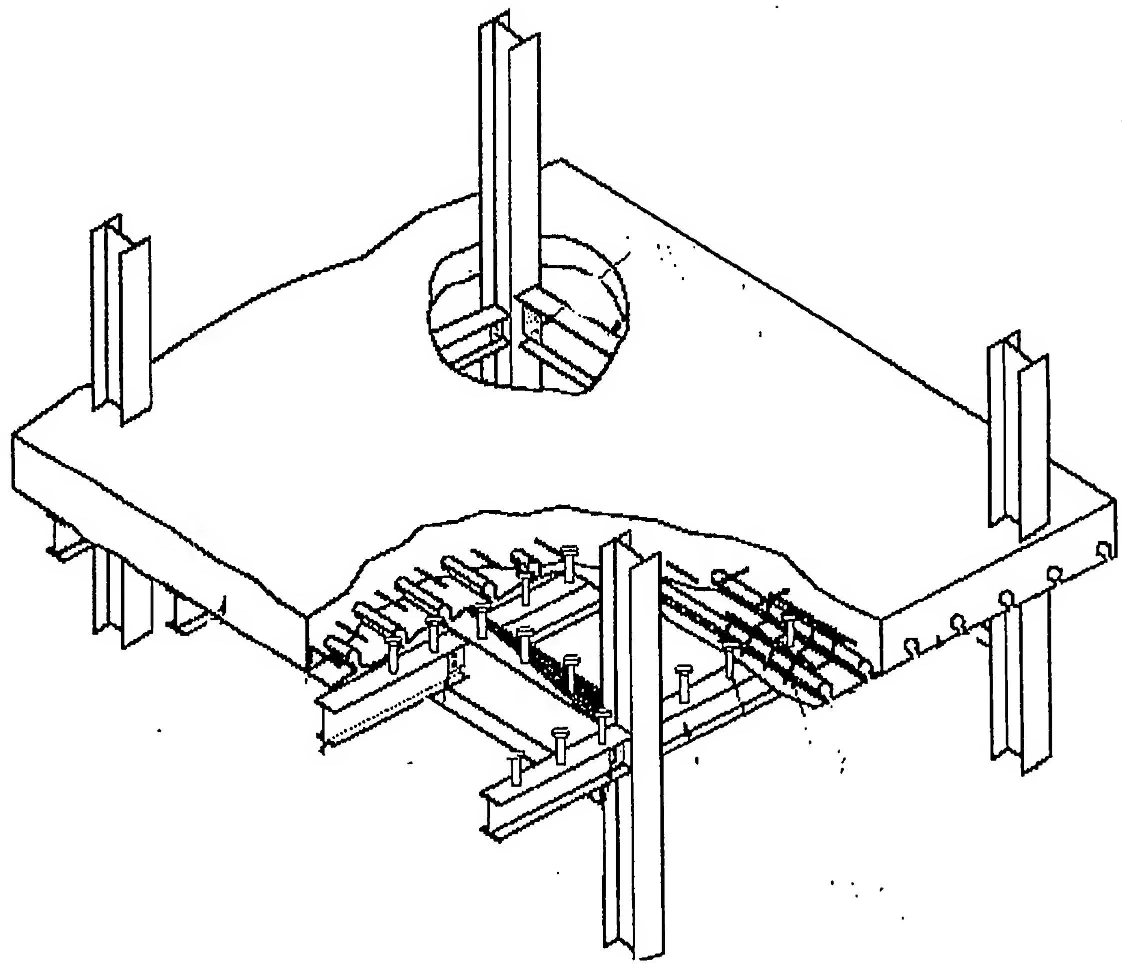
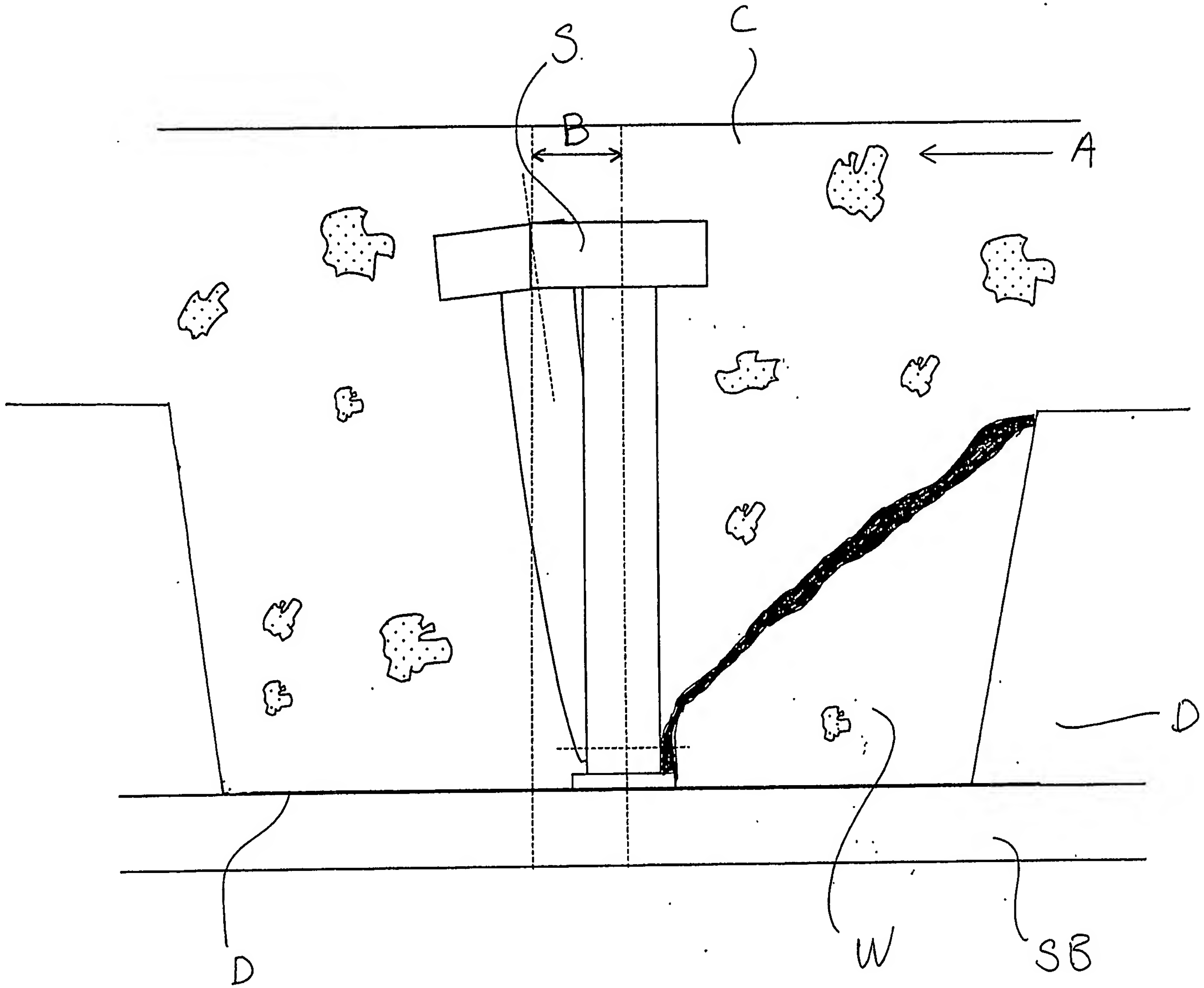


FIGURE 2A



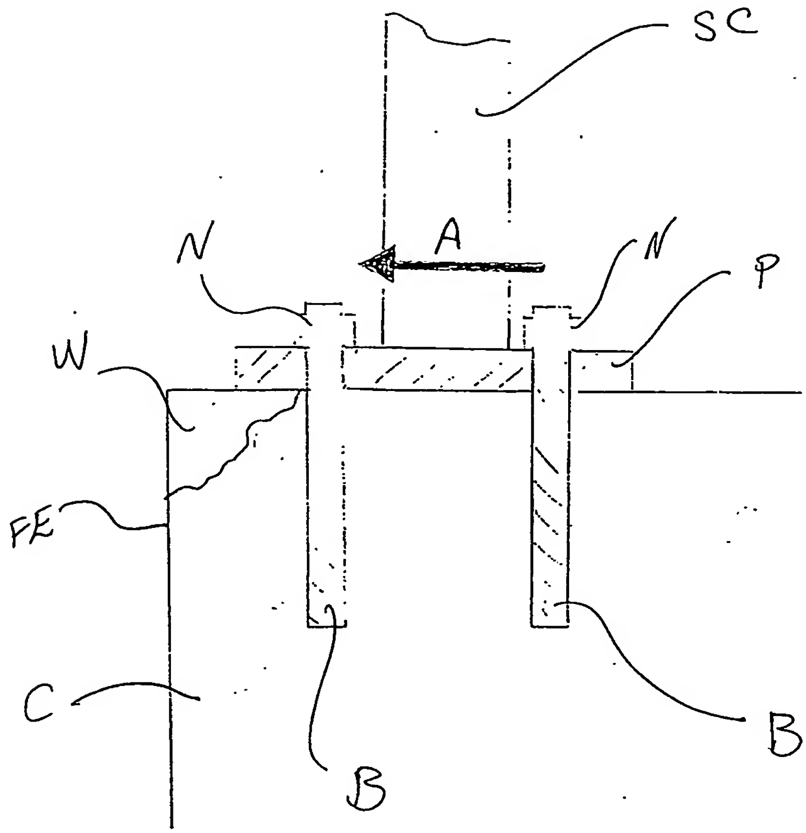


FIGURE 2B

FIGURE 3

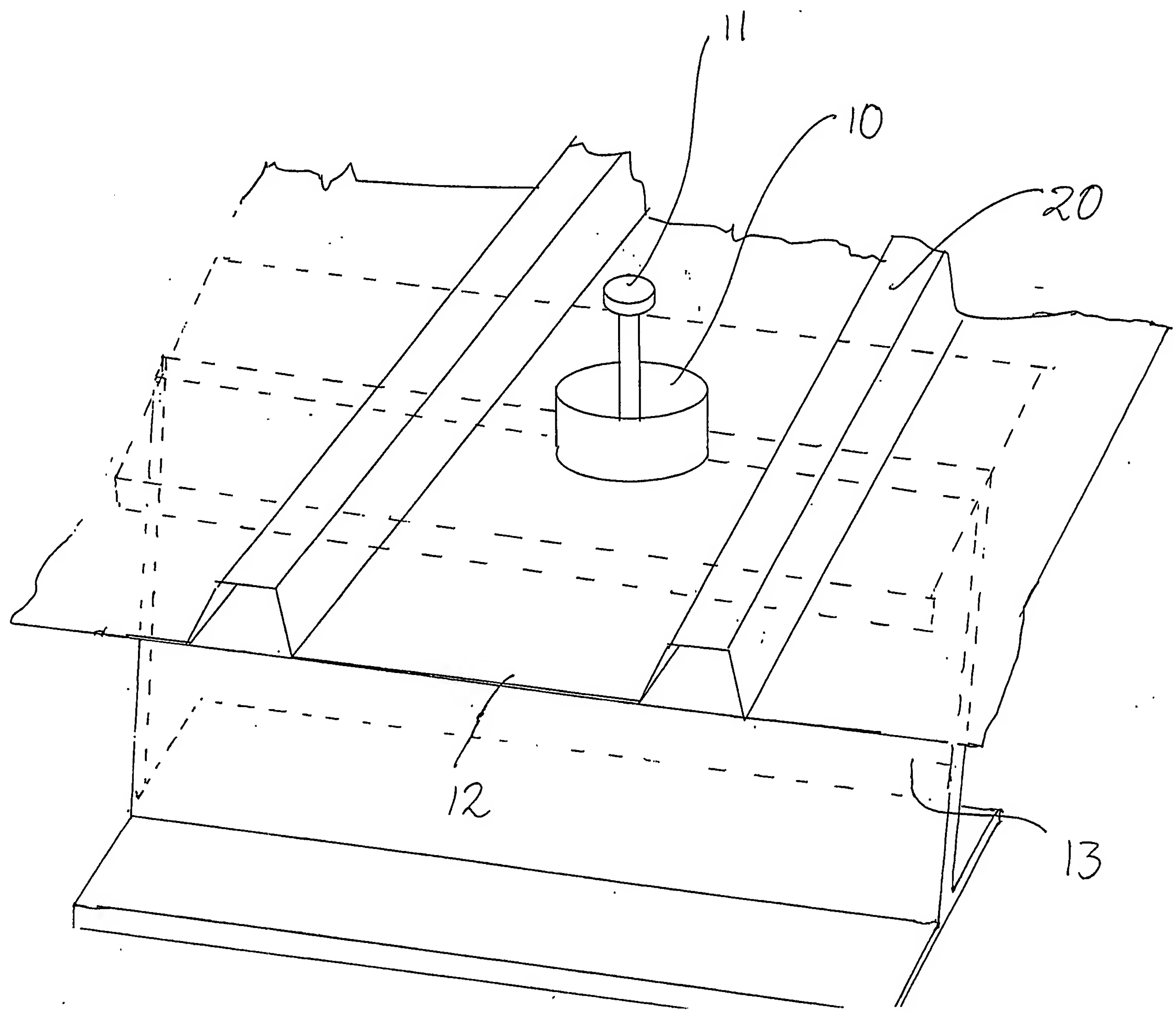


FIGURE 4

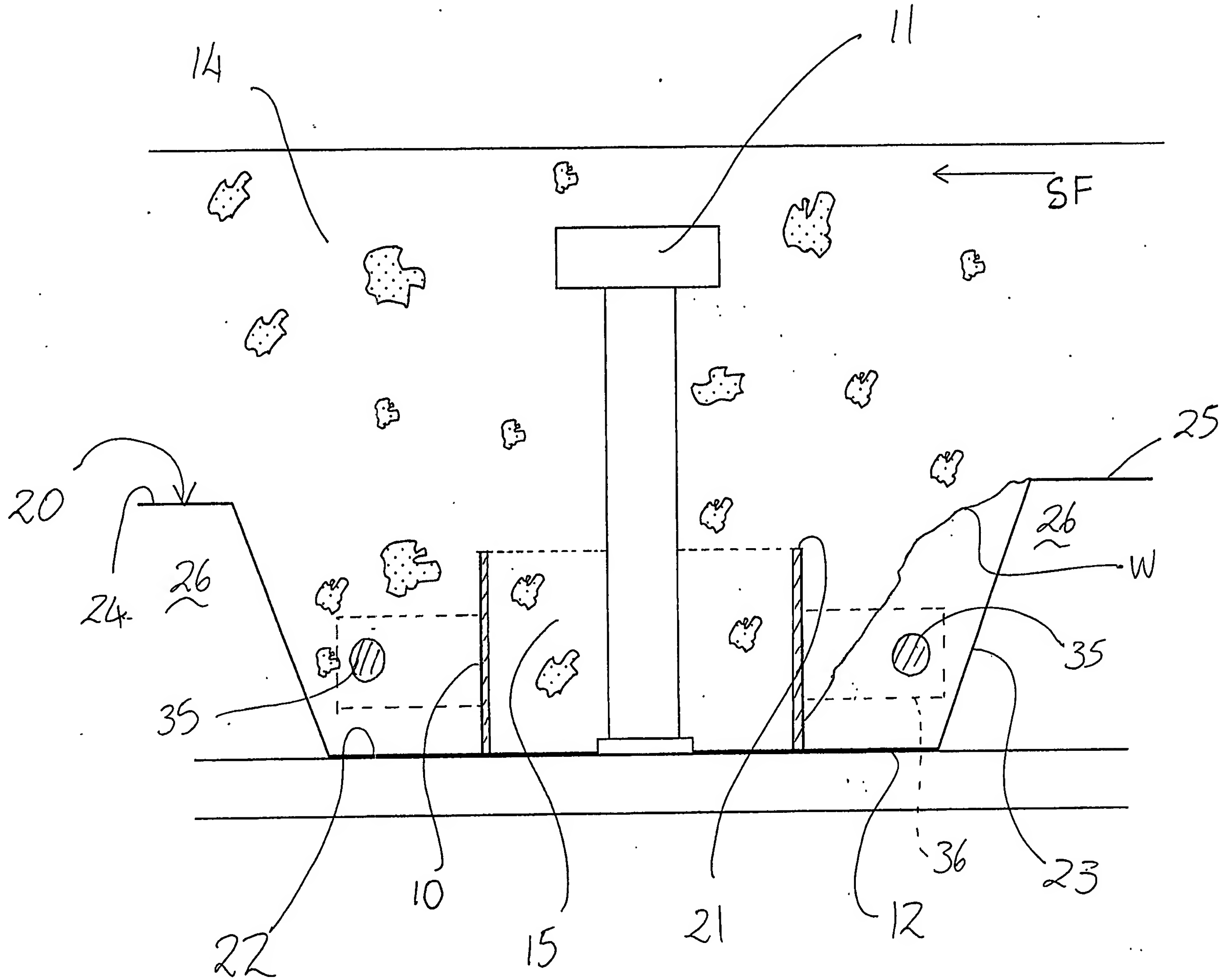


FIGURE 5

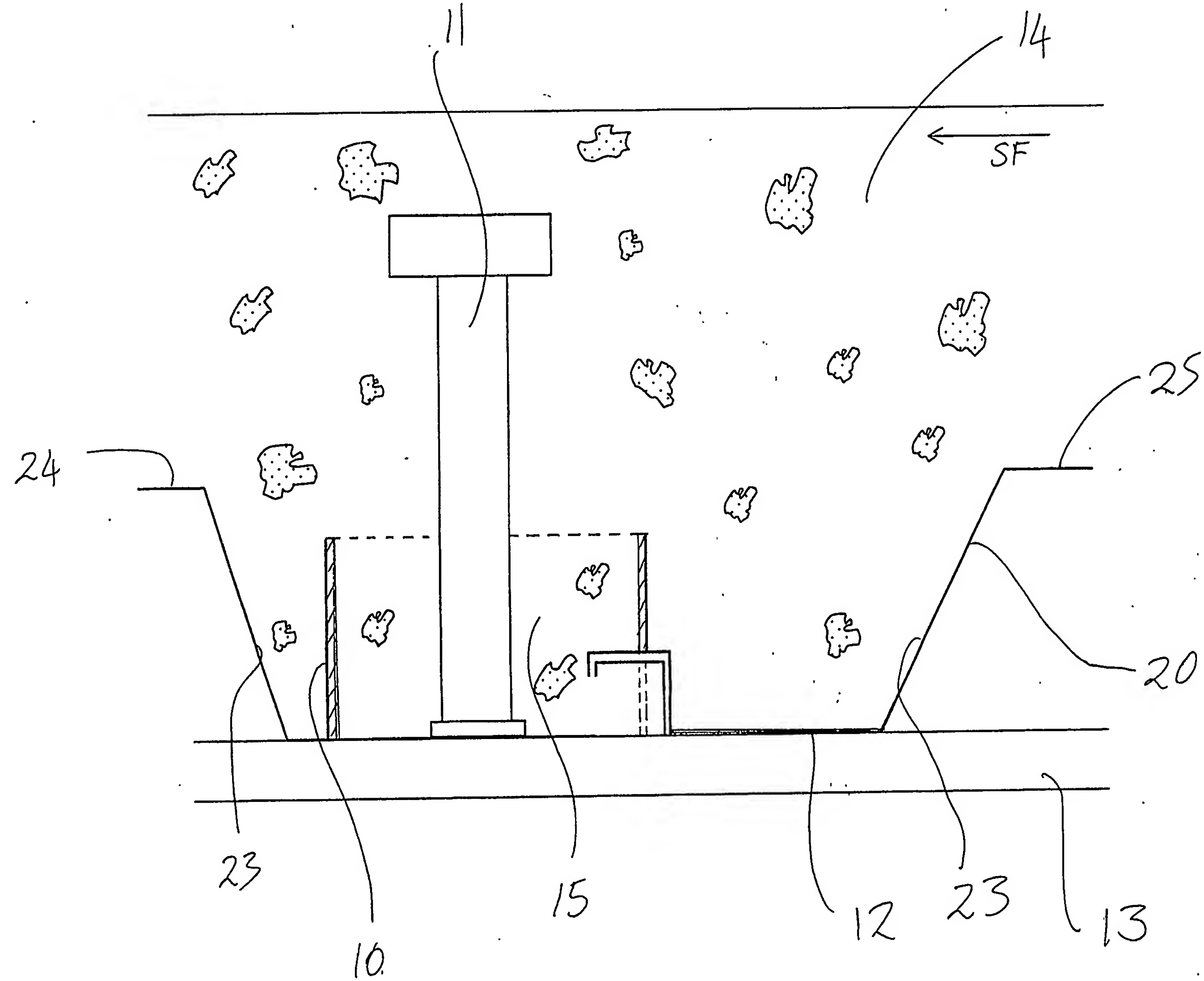
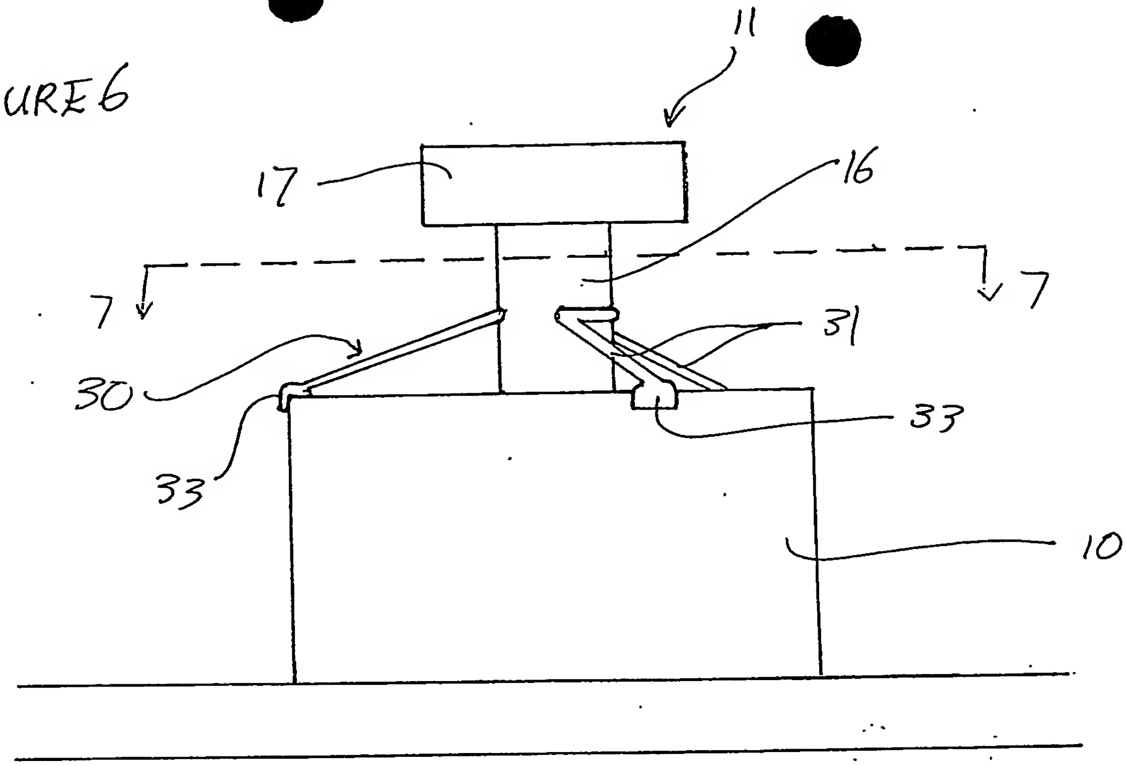


FIGURE 6



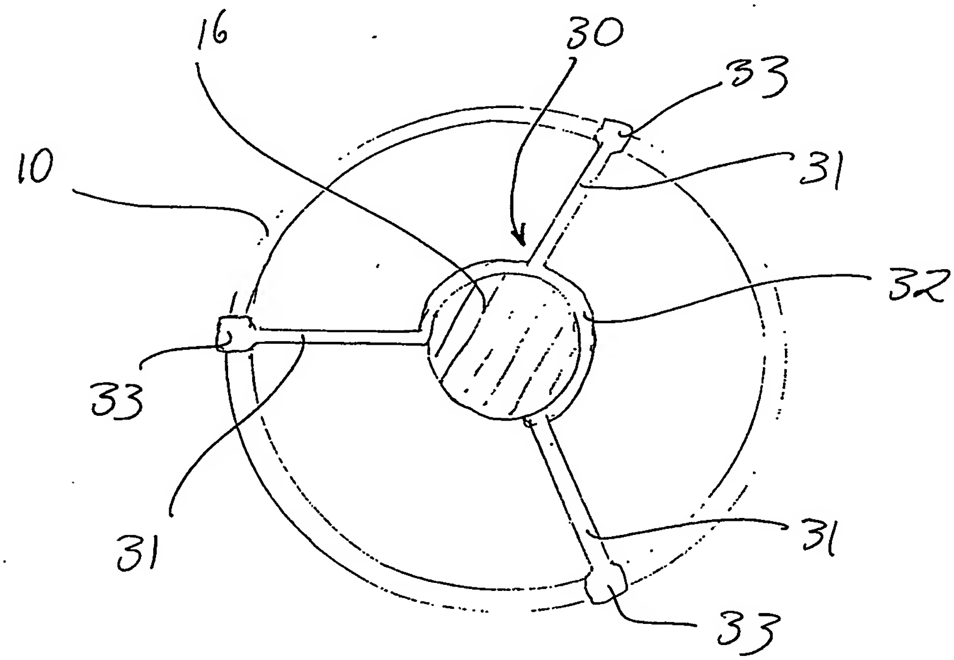


FIGURE 7

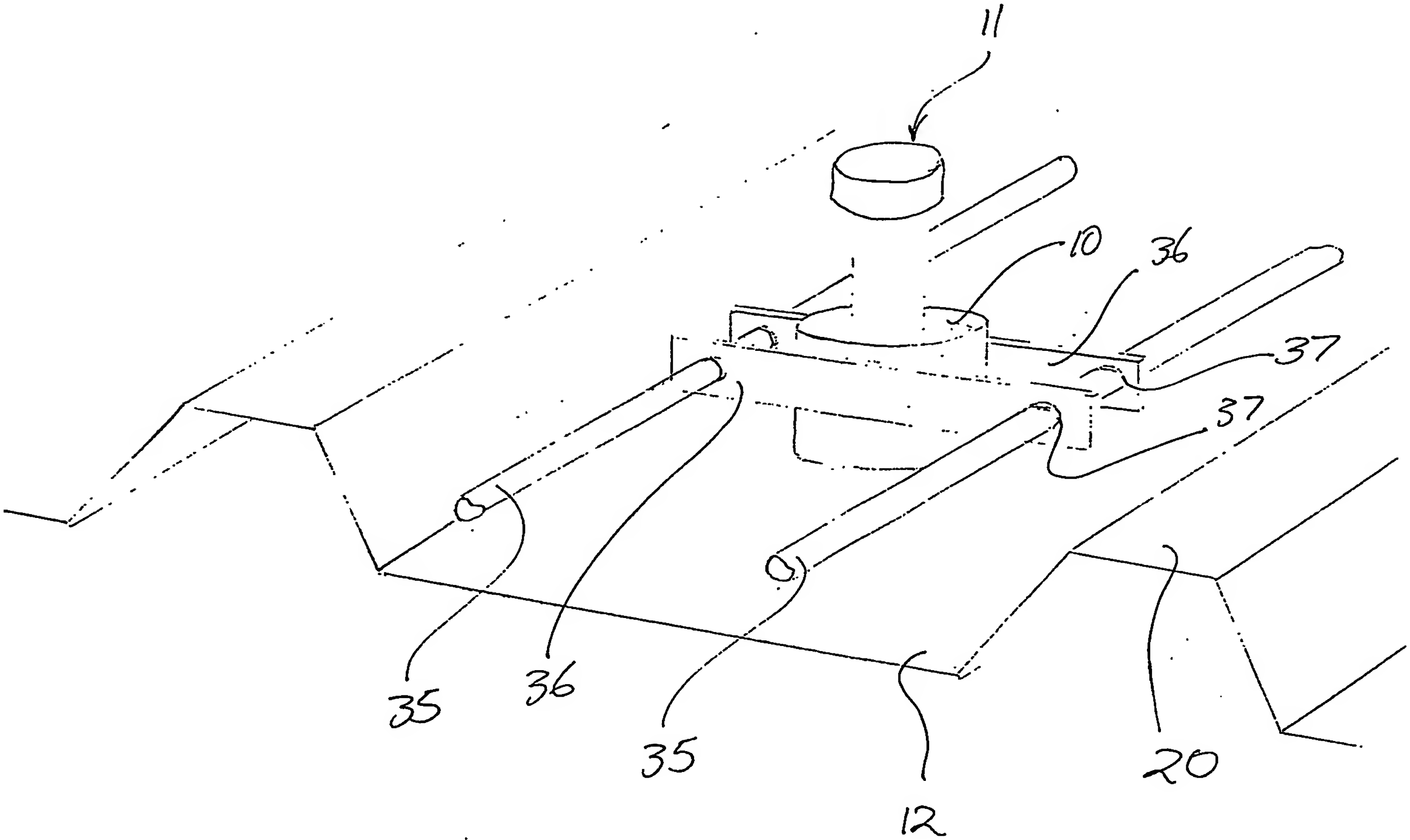
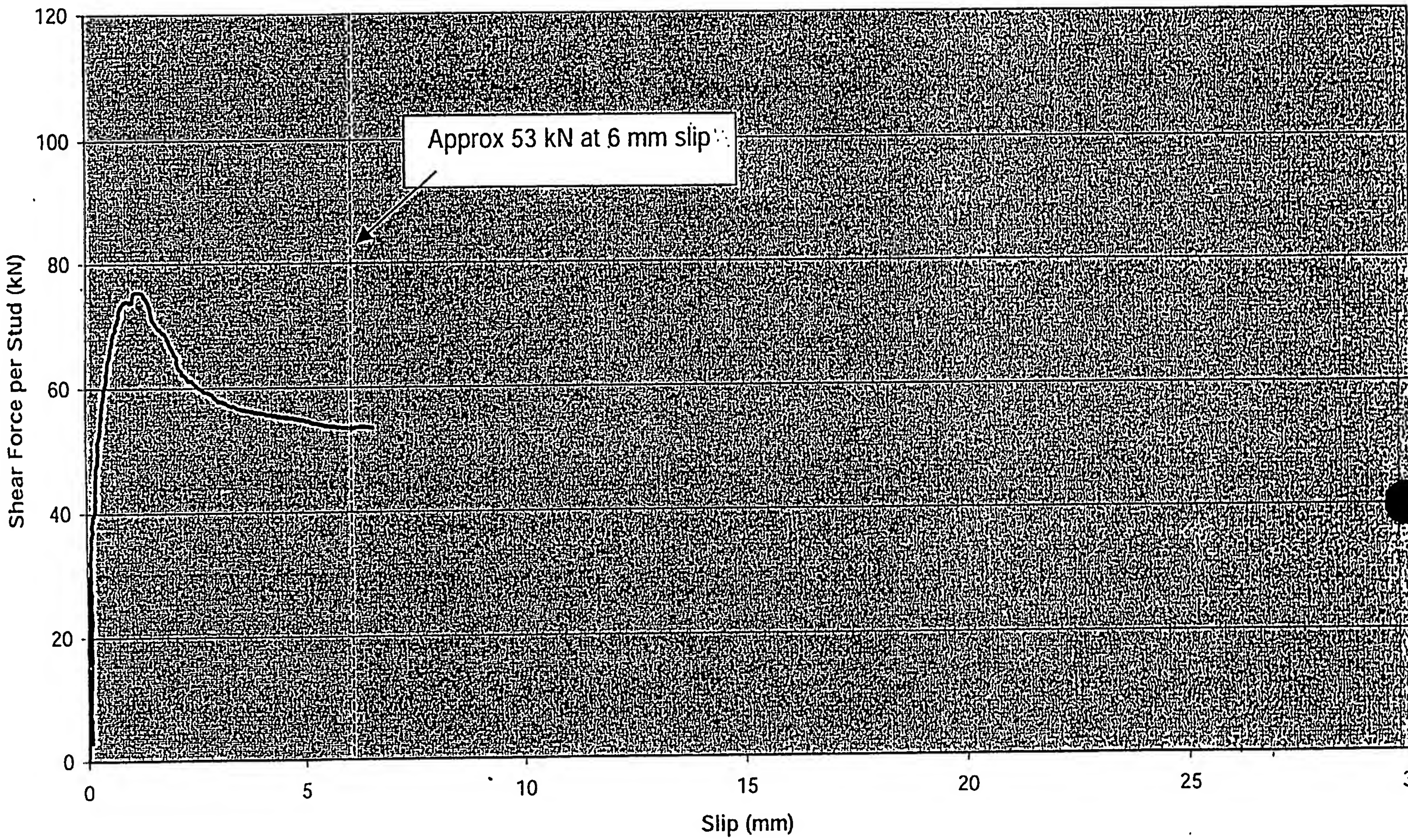


FIGURE 8

FIGURE 9



Approx 53 kN at 6 mm slip
Shear Force per Stud (kN)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Slip (mm)

FIGURE 10

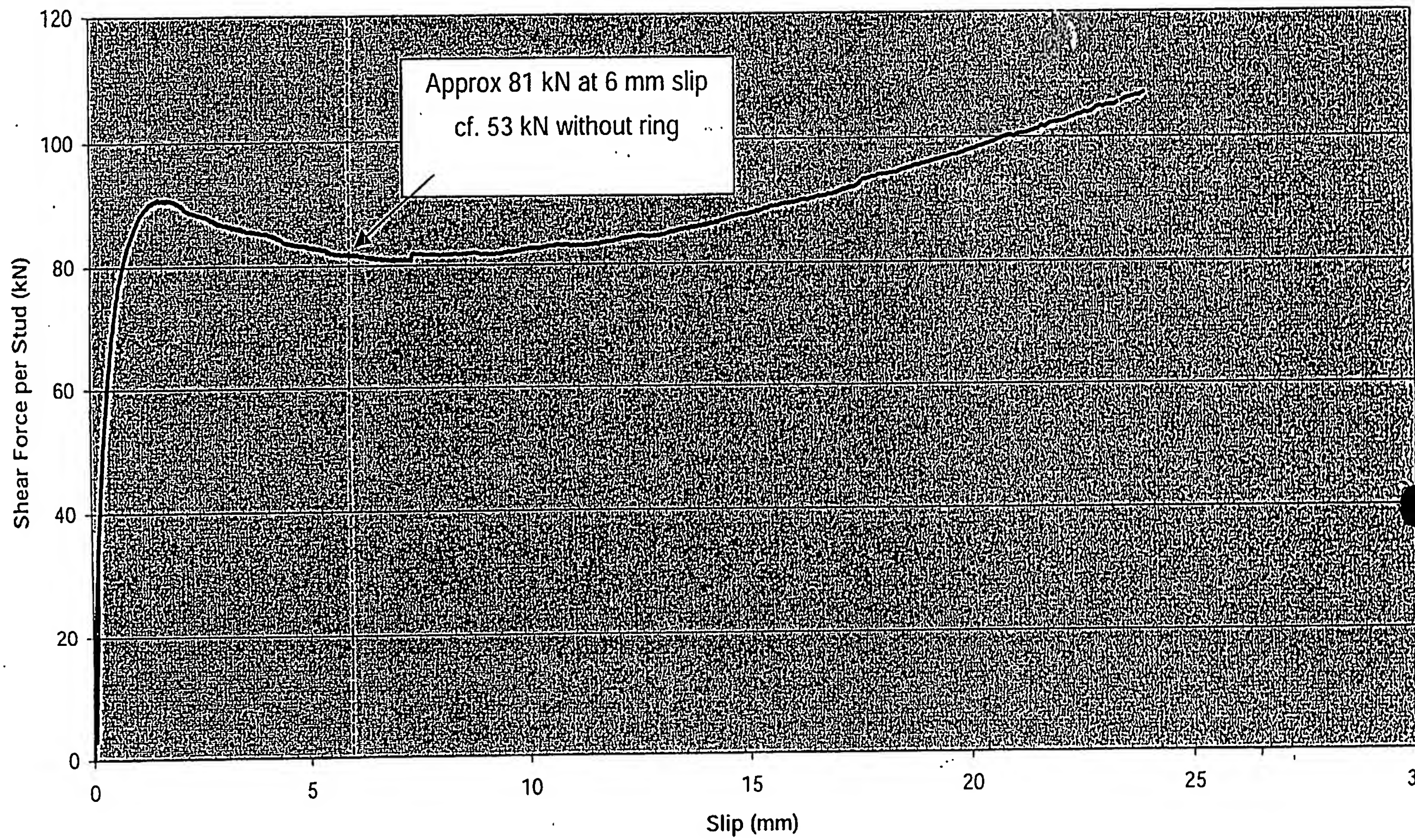
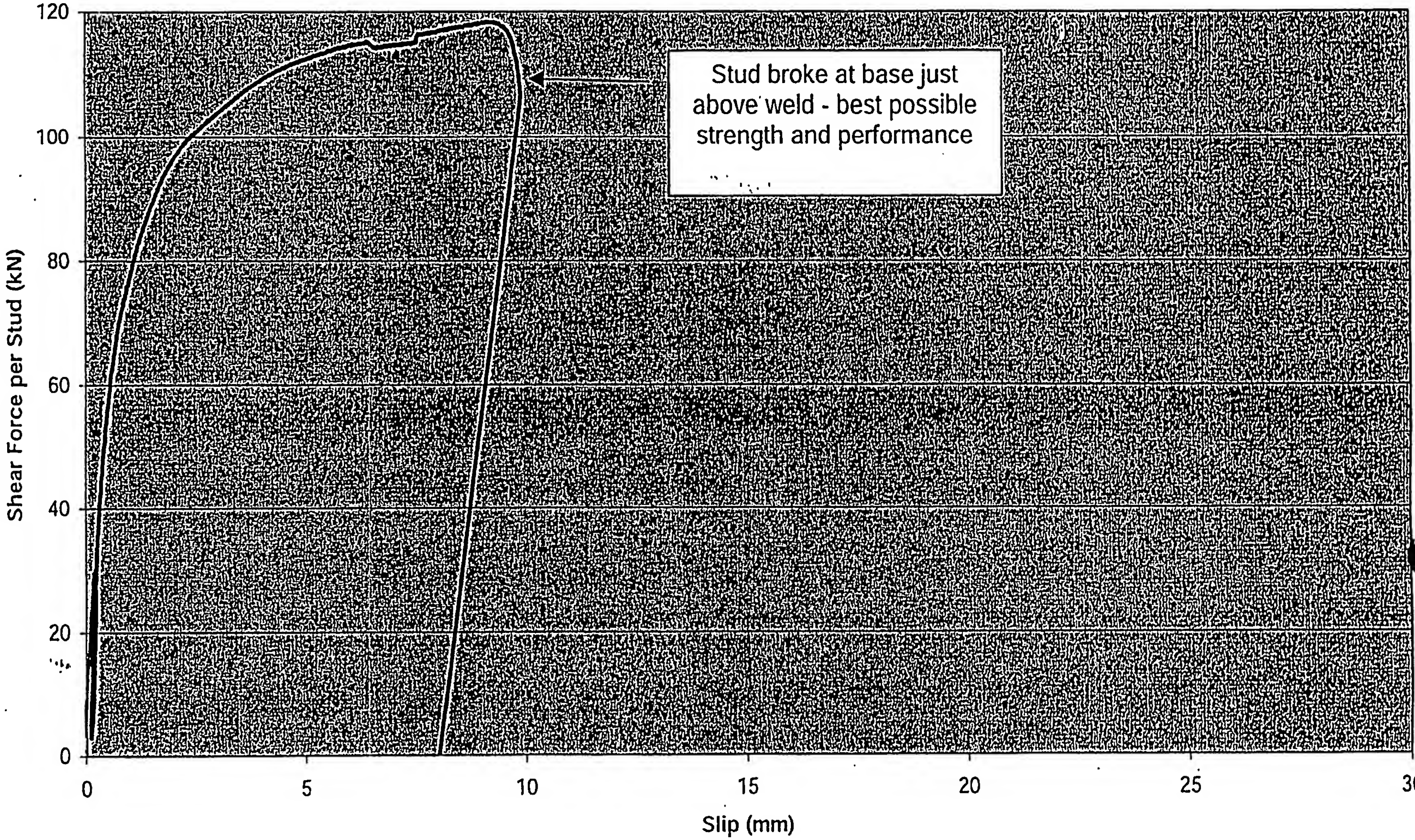

Approx 81 kN at 6 mm slip
cf. 53 kN without ring
Shear Force per Stud (kN)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Slip (mm)

FIGURE 11



Stud broke at base just above weld - best possible strength and performance
Shear Force per Stud (kN)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Slip (mm)